ARMY RESEARCH LABORATORY

Soldier Performance Course of Action (COA) Visualization Aids

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ARL-CR-302 AUGUST 2000

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DAAD17-99-P-0203

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Aberdeen Proving Ground, MD 21005-5425

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Abstract

The computer revolution has resulted in extending the possibilities of battlespace visualization to the brigade commander and below. However, mobility and bandwidth considerations require that the systems be efficient to reflect the realities of modern combat. The Advanced Battlespace Architecture for Tactical Information Selection (ABATIS) is being developed to be a rapid planning and re-planning experimental environment. ABATIS's object-oriented architecture has the advantage of being able to rapidly construct a three-dimensional battlespace that will accurately represent the essential planning components of a brigade and smaller division battle environment. The basic architecture has been extended to include war-gaming logic as part of the software design, and examples are given that pertain to specific military problems. This capability will allow ABATIS to realize fully the implications of battlespace visualization by creating a human-computer synergy that encourages both human and machine to generate and evaluate possible courses of action and their consequences. The human performance implications are discussed, and particular attention is directed toward research issues related to terrain visualization, automation, decision making, and cognitive biases.

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1. Introduction

The human's ability to visualize complex problem spaces is an important part of both scientific and military lore. Ulysses S. Grant, for example, could not only visualize minute details of the impending battle area but could actually envision troop movements and bottlenecks while planning his tactical maneuvers (McPherson, 1999). The purpose of this research project is to extend this capability via modern computer technology that symbolically abstracts the most important features of the battlespace, including the behavior of U.S. and enemy forces. The research focus is the cognitive and perceptual performance of the combined human-computer system. To support the research program, the authors created a specialized software system called "Advanced Battlefield Architecture for Tactical Information Selection" (ABATIS) (Keane, Rozenblit, & Barnes, 1997). ABATIS is a three-dimensional (3-D) visualization system that facilitates rapid, flexible development of high-level battlespace representations as well as execution and assessment of war-gaming scenarios.

This report discusses recent refinements of the ABATIS system, which will eventually extend the visualization domain into human-computer research paradigms via intelligent algorithmic modules. The refinements follow directly from the meaning of visualization that implies understanding the process and "end states," not simply presenting finely grained detail of the physical world (Barnes, 1997). The extensions of ABATIS will allow the quick creation of new tactical environments, investigation of optimal U.S. and enemy end state behaviors, and better understanding of the human role in this symbiotic environment.

Our focus is narrowed to the interplay of tactical decision making, situational awareness, and the continuous planning process via intelligent aiding. Our concerns are the cognitive problems associated with visualization and operator performance in automated planning environments, particularly, in situations when the planner must address multiple sources of uncertainty. Recent analyses of automated systems indicate that the extent to which human operators mistrust or conversely over-rely on automated systems depends on their state of situational awareness (Parasuraman & Riley, 1997).

The principal issue is the ability of the human to understand enough about the planning scenario and the behavior of the intelligent systems to make well-informed supervisory choices without losing insight into the unfolding battle trends. Intelligent systems can remove the operator from the decision process

and inadvertently create a situation in which the human can no longer react to new developments. Conversely, the human may not trust the computer solution and may choose to follow his or her own instincts when they are inappropriate. We hypothesize that both situations have the same root cause (the inability of the decision maker to visualize the broader military context while understanding the implications of the suggested courses of action [COAs] proposed by the automated system). Using ABATIS, we intend to investigate better visualization techniques whose purpose is to impart insight as well as suggested decision options during the planning and re-planning process. Our research goal is a human-computer synergy that decreases planning time while maintaining the intuition and insight of the human component through combining the explanatory power of visualization with the computing power of intelligent systems. We intend to establish the utility of ABATIS as a research tool and as an early prototype of a versatile planning and re-planning tool for "brigade-and-below" applications.

2. Background: Human Performance Issues

2.1 Terrain Visualization

ABATIS supports a 3-D perspective military terrain generator that can be viewed from multiple angles and perspectives. The 3-D effects are produced by renderings that depend on perceptual factors such as volume, perspective, shading, and relative size to produce the desired effects. A variety of issues related to terrain visualization was investigated by the University of Illinois researchers (Banks & Wickens, 1999; Wickens, Thomas, Merlo, & Sehchang, 1999). The two principal foci of this research were the effects of visualization dimensionality and viewpoint. A common assumption among display designers is that 3-D perspectives are the preferred presentation mode for military terrain because these perspectives are similar to the natural world. However, converting 3-D information onto a two-dimensional (2-D) display plane introduces perceptual ambiguity because of foreshortening and resolution losses in the depth dimension. For example, a number of experiments investigating aircraft display formats indicate poor resolution in the altitude dimension for air traffic control tasks whenever the observers were using 3-D as opposed to 2-D representations (Merwin, O'Brian, & Wickens, 1997). Other problems related to altitude and azimuth determinations have been noted for navigational tasks that required 2-D map to 3-D scene translations (Schrieber, Wickens, Goetz, Alton, & Hickox, 1998).

In an extensive survey of aircraft-related research, Banks and Wickens (1999) found many cases in which 2-D display representation was superior to the higher dimensional representations and vice versa. Based on these findings, they

investigated military map problems using U.S. Military Academy cadre as subjects to investigate the following map tasks: assessing mobility corridors, relative position judgments, and line-of-sight (LOS) determinations. Again, the relative advantages of dimensionality were highly task dependent; only the LOS tasks showed any clear advantage for the 3-D conditions. The other variable that they investigated was the degree of exocentricity (i.e., the relative distance of the viewer above the scene). Extreme exocentric conditions involved a bird's eye view of the terrain, whereas the closer egocentric conditions involved an immersed view as if the operator were observing the terrain from a low altitude.

In the immersed conditions, the observer could move freely within the terrain boundaries. The results were similar to dimensionality results in that the advantages of viewpoint depended on the particular military task and dependent measure. For example, LOS tasks resulted in more accurate LOS determinations for immersed views but at the expense of increasing the total time spent performing the task. In an ensuing study, Wickens, Thomas, Merlo, and Sehchang (1999) focused on potential cognitive problems associated with being immersed within the terrain scene. Again, using U.S. Military Academy cadre, they discovered a cognitive tunneling effect for the immersed condition. This effect resulted from subjects' inattentiveness to important military events occurring to their rear in the immersed map environment.

Other researchers investigated similar viewing factors via a more abstract scientific data visualization paradigm. When the observer was required to navigate and make relational judgments in 3-D data space (McCormick, Christopher, Banks, & Yeh, 1998), degree of exocentricity was an important factor. However, the results were not monotonic; intermediate views (half way between immersed and bird's eye) actually resulted in slower search performance than either extreme. Apparently, this view had neither the advantage of the proximity of the immersed view nor the overall contextual superiority of the exocentric view. In general, the results followed the expected pattern: tasks that required local judgments were better supported by immersed views and those tasks that depended on global cues were better supported by exocentric views. Wickens, Merwin, and Lin (1994) investigated the effects of dimensionality on information integration tasks. Three-dimensional representations resulted in better integration among the cognitive dimensions of price, debt, and earnings as opposed to 2-D planar representations (requiring integration over two displays) of the same information. Also, stereopsis (ocularly induced as opposed to 3-D renderings) aided in information integration. Interestingly, the 3-D performance gains were not evident during ensuing memory tasks.

There are three ways to produce 3-D effects: perspective renderings, stereopsis (based on binocular effects of retinal disparity), and motion induced (Kaiser & Proffitt, 1992). These 3-D factors act in concert with each cue that contributes to

the scene's realism as an additive weighted component (Sollenberger & Milgram, 1993). Stereopsis and motion-induced effects improve performance of certain tasks (Barfield & Rosenberg, 1995; Yeh & Silverstein, 1992), but they have their own set of problems that are beyond the scope of this research effort (Mon-Williams & Wann, 1998; Patterson, Moe, & Hewitt, 1992). Our initial efforts concentrate on 3-D rendering cues and the results will be used to develop overall guidelines for the use of viewpoint (viewing angle and immersion factors) and dimensionality to enhance tactical decision tasks (Barnes & Wickens, 1998). The results will delineate how best to use the versatility of ABATIS to accurately portray military scenarios within a process-centered environment.

2.2 Tactical Decision Making

For the most part, this research studied perceptual and cognitive effects related to situational awareness (Endsley, 1995). ABATIS is being designed to investigate the synergy between computer visualization and artificial intelligence and their combined effects on the war fighter's tactical decision making. Other researchers have concentrated on the soldier performance effects of combining these two components (Marshak, Winkler, Fiebig, Stein, & Khakshour, 1999), and important research continues in visualization factors related to soldier immersion and dimensionality (Wickens, Thomas, Merlo, & Sehchang, 1999). However, more research needs to be done which focuses on the relationship of human uncertainty to automation. A recurring problem with automated systems is trust (Parasuraman & Riley, 1997). In particular, early decision-aiding approaches tended to be sophisticated in a technical sense but naïve in a practical sense; experts did not know when to trust them.

This lack of understanding of the computational processes of intelligent systems can lead to two seemingly unrelated system deficiencies: complacency and mistrust. Both conditions result at least in part from the human viewing the intelligent algorithm as a separate or even a competing entity. The crucial factor underlying both mistrust and complacency is the lack of insight by the human operator as to exactly what it is the machine is doing over some extended period of time. Unfortunately, the problem is complicated further by the behavioral characteristics of humans when they reason while in uncertain environments. In the last 25 years, a seemingly never-ending list of human biases, limitations, and psychological illusions has been documented in the behavioral decision literature (Kahneman & Tversky, 1973; Einhorn & Hogarth, 1981; Hollands & Wickens, 1999). The usefulness of probabilities is a controversial subject. In the popular book "A Civil Action," for example, the evidential propriety of probabilistic information in general was challenged by the defendant's lawyers (Koehler, 1993). Logically, not assigning a number to an uncertain event does not make it deterministic, and yet probabilistic evaluations of possible future COAs are resisted by military leaders for a number of reasons, not the least of which is the difficulty of generating valid probability values. New systems are being developed which will generate probabilities for possible intelligence outcomes

(Jones et al., 1999; Charles River Analytics, 1998), but the results depend on the ability of trained analysts to generate accurate probabilities. Again, the basic issue is trust. The user of intelligence estimates must trust the intelligent algorithm and the probability elicitation process that feeds the algorithm.

2.3 Poor Calibration of Probability Estimates

The overconfidence phenomena have been documented by a number of researchers (Sniezek & Buckley, 1993; Hollands & Wickens, 1999). The basic paradigm is to ask human subjects to answer a general knowledge question and then state their confidence level. The accurate confidence level should correspond to the overall percentage correct on the general knowledge test. In fact, humans tend to be over-confident by 20% to 30% (obtained score – average confidence level). This phenomenon extends to experts of all types, novices and college students; weathermen seem to be the one of the few groups that is well calibrated. Sniezek and Chernyshenko (1998) recently replicated this phenomenon at the U.S. Army Intelligence Center and Fort Huachuca, Arizona, by using senior retired intelligence officers. The impact on intelligence estimates is obvious; senior officers do not like to be wrong, and yet, the numeric confidence levels they assigned to their answers were consistently overly confident. The other side of the coin is that the operator's use of probability estimates displayed on the computer does not always follow prescriptive decision rules. One such deviation from normative behavior is the phenomenon of probability matching: the tendency of humans to match rather than optimize probability sequences. This is related to gambler's fallacy and the tendency of the decision makers to be influenced by previous outcomes for independent events. An example from one of the author's personal experiences is the tendency of subjects to override automatic target recognition (ATR) algorithms when it is inappropriate to do so (their performance was actually less than chance). In this particular case, the operator tended to match the stated accuracy level of the ATR as if he or she felt compelled to override the system a certain percentage of the time even though objectively, the operator performance was quite poor in these circumstances. The overall research results suggest that the human operator is poorly calibrated in both using and generating probabilistic information (Barnes, 1979; Hollands & Wickens, 1999). Sniezek and Chernyshenko (1998) have designed research and training stratagems to alleviate the latter problem; our research interests are focused on visualization techniques to improve the user's ability to understand and use probability estimates generated by the computer.

2.4 Confirmation Bias

Many of the biases discovered in the literature are attributable to human processing limitations (March, 1978). Of particular importance in a military setting is the sequence of when information is processed and its effect on decision making. The USS Vincennes incident is a good example of one manifestation of sequence effects. The initial reading of the screen suggested to the radar operator that the incoming plane was descending with hostile intent.

Later evidence indicated the aircraft was neutral and ascending, but the action officer and the commander were looking for evidence of immanent attack, and thus, the initial decision was amplified rather than contradicted as new information was received (Hollands & Wickens, 1999). Adelman, Bresnick, Black, Marvin, and Sak (1996) found a similar overweighing of initial cues for Patriot air defense officers who were more influenced by the action of the incoming aircraft if the action was done early in the sequence as opposed to the same objective pattern with the cues occurring late in the sequence. This seemed to be another example of the decision maker forming an hypothesis early and favoring cues that supported the hypothesis while discounting equally valid cues contradicting it. The problem is more complex than these examples indicate because there are also cases when the opposite occurs. A number of experiments have demonstrated a recency effect; cues that are later in the sequence have more impact than the earlier information even for similar tasks (Adelman & Bresnick, 1992). Hollands and Wickens (1999) argue that the simplicity of the initial cues and the length of the set of updating cues may explain the difference. In the Vincennes incident, the hostile hypothesis was generated early and events occurred quickly. Perhaps in cases when the initial hypothesis is less firmly held and the intervening information unfolds over a longer time period, recency of information outweighs the initial direction of the data sequence. It should be obvious that both instances are valid strategies for overcoming processing limitations, allowing the observer to concentrate on the most crucial information rather than be overwhelmed by the constant data stream. Both tactics have ecological validity. Forming an early hypothesis and collecting data related to the hypothesis are effective means of handling complex data spaces. In combat, changing the hypothesis often may be worse than "sticking to your guns" once you have reached a conclusion unless the disconfirming evidence is strong.

On the other hand, recency effects may be justified in a volatile environment wherein the initial information is no longer valid. In general, the perceived validity of intelligence degrades as a function of time. The sequence in which combat information is received and the early formation of hypotheses concerning enemy intent are important cognitive factors in explaining the relative effectiveness of different combat planning conditions. It will be important to know in particular whether information collected early in the planning process is assigned too much or too little weight as more recent intelligence is collected. This particular problem is expected to interact with validity estimates of intelligence sources and the general problems associated with probability estimation. Both of these issues will interact with visualization; the more graphic and compelling the battlespace image, the more likely the user will be to assign too much weight to probabilistic cues and to prematurely choose a COA that more recent information may contradict. The challenge is to develop visualization principles and feedback techniques that impart insight into the probabilistic nature of the process, including the possibility of abrupt change. The objective of the ABATIS research environment is to understand the effects of

these psychological factors in a rapid planning and re-planning tasking for a versatile, highly mobile force.

The following describes the general architecture of ABATIS, future extendibility, and the military context it is being developed to investigate. The overall purpose of the research project is to determine general design principles for these situations, which are based on realistic soldier performance and cognitive parameters.

3. ABATIS

The U.S. military extensively employs simulation-based, virtual training systems known as computer-generated force (CGF) systems (Hancock, 1994; Karr, Reece, & Franceschini, 1997). Such systems incorporate live, virtual, and constructive simulation in high resolution, synthetic environments. The disadvantages of these systems are the complexity of communication protocols they require when used in a distributed setting and high communication bandwidth constraint. By design, they do focus on battlespace abstractions; their goal is to replicate a battle environment in a computer-based system so that training costs can be reduced.

Examples of systems that share some similarities with our visualization environment are JANUS(A)[1] and, more recently, commander's intelligent battlefield information display (CIBID) and virtual geographic information system (VGIS). JANUS(A) is used by the U.S. Army as an interactive, computer-based, war-gaming simulation of combat operations conducted at the brigade and lower levels. It consists of two opposing forces that are controlled by two interacting players. JANUS(A) concentrates on ground combat. It is composed of Army-developed algorithms and data to model combat processes. The program comprises approximately 200,000 lines of legacy code (VAX [virtual address extension]-11 FORTRAN [Formula Translator], a structured Digital Equipment Corporation [DEC] extension of American National Standards Institute [ANSI] standard FORTRAN-77). This aging technology seriously impedes any efforts to implement the concepts required by the commander's post of the future.

The CIBID software architecture currently being developed by CHI (computer-human interaction) Systems, Inc. (Graves & Miller, 1998), is a 2-D battlefield visualization tool that uses object-oriented design principles. Users can work with digitized maps to create a battle scenario via the existing 2-D Army symbology. facilities are provided to execute war-gaming scenarios in a model-based environment.

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[1]not an acronym

VGIS allows interaction and navigation in very large, high resolution, dynamically changing databases while retaining real time display (Haus, Newton, Ribarsky, Faust, & Hodges, 1996). It renders 3-D "realistic" terrain from an immense database of terrain data. This requires a significant computational and bandwidth overhead. Although a high degree of terrain realism can be achieved in VGIS, no 3-D symbology and model libraries are available.

The need is well recognized in the cognitive psychology literature (Barnes, 1997; Bennett, Toms, & Woods, 1993; Modrick, 1976; Paquet, 1992) for displays that are *process centered* and provide innovative visualizations and symbolic content. We intend to extend these cognitive engineering principles into the realm of 3-D real-time animated military planning. Our work attempts to meet the following desiderata for process-centered displays postulated by Barnes (1997): (a) develop objects that indicate the state of the events being displayed; (b) capture behaviors and rules of behavior; (c) represent possible end states for current battle trends; (d) represent process, goal, and environmental indicators; and (e) provide a means of executing and assessing various war-gaming scenarios.

We now describe the underlying system software architecture, recent improvements, and the continuous process of upgrading the software to enhance the ability of ABATIS to incorporate intelligent modules as visualization drivers. We show a realization of a war-gaming scenario fashioned after FOX-GA[2] (Schlabach, Hayes, & Goldberg, 1999), a genetic algorithm developed at the University of Illinois.

4. Software Development

Existing battlefield visualization systems typically exhibit high resolution and high realism. Their drawback is the lack of flexibility in modifying the symbology and war-gaming scenarios as well as the high overhead associated with the communication bandwidth that they require, especially when these systems are exercised in the intensely collaborative setting where such activities take place. The awareness of the tactical situation does not require all the details that such systems attempt to capture.

A number of themes should underlie any new architecture for battlespace visualization. Most importantly, the architecture must facilitate understanding of the *process* of the battle, rather than simply the current location of various forces. This requirement implies that the system should reflect how the user assimilates battlespace state information into a process-centered viewpoint. One aspect of this problem is the assembling of individual units of information into context-

[2] not an acronym

rich, higher level composites. Another is the presentation of this derived information in a way that is intuitive to the human user.

Motivated by these desiderata, the developers created the ABATIS system. Our key concept in the design of ABATIS is the process-centered display (PCD), a construct that can display complex, evolutionary processes as well as simple state changes (Keane, Rozenblit, & Barnes, 1997).

The main goal of the PCD's design is to convey the *processes* that are occurring in the battlespace. Since battlespace processes (e.g., maneuver, attack) evolve and change as the battle unfolds, the architecture must also support dynamic change and evolution at "run" time. Given the vast range of possible battlespace scenarios and objects, the architecture must also be flexible enough to permit the quick creation of new battlespace objects from old ones.

A secondary goal is to focus on the possibility of using motion, color changes, "morphing," or other types of animation to convey information. Some uses of animation are obvious, such as moving a symbol from one location to another. However, abstract quantities can also be tied to motion. A simple example would be allowing the strength of a ground force to be represented by the speed of rotation of its symbol. When done in a way that matches the intuitive notions of the user, such a presentation of information becomes a *metaphor*. The metaphor correlates familiar experiences with the actions of symbols on the computer display.

A final goal is to allow arbitrary levels of complexity in both the battlespace objects and their associated process dynamics. This complexity is needed to accurately model the intricate dynamics of a real battlespace and its metaphorical representation. Driven by these goals, the architecture for the ABATIS-PCD is designed using the object-oriented software design paradigm.

The fundamental design concept of ABATIS is the modularity of display elements. Terrain and unit elements are represented by symbols (objects) that can reside in libraries and can be placed on the display at any location and in any orientation. As opposed to the traditional paradigm of incorporating attributes and methods in object descriptions, we specify the behavior of such elements as distinct, generic entities that can be associated with the battlespace elements.

The process-centered display requires simple, fundamental classes from which instances of battlespace representations of any complexity can be rapidly constructed. More specifically, such classes are terrain, unit, behavior, and information (attributes). Unit objects can be built from elementary graphical elements (GRELS) (e.g., to construct a 3-D battalion symbol, we can use a rectangle, diagonals, and two vertical bars). New elements (with a more complex structure) can be created from the existing elements and can be stored in

libraries. Thus, re-use and rapid construction of battlespace instances are facilitated.

The prototype of the ABATIS design has been implemented on the Silicon Graphics Octane machine, in the C++ programming language, using the Open Inventor™ development environment. The system's major capabilities are that it can

1. Load terrain elements, military units, and tactics into a scenario creation area.

2. Import any 3-D model specified in the Open Inventor™ format.

3. Construct objects from fundamental elements in the object creation window.

4. Replace a terrain or unit fundamental element.

5. Transfer fundamental elements to the scenario window to location (x, y, z).

6. Dynamically specify length and width of terrain size and scale objects and grid size.

7. Attach a behavior to a fundamental element in a scenario window.

8. Animate objects individually or synchronously.

9. Move an object according to a route by specifying a corresponding path name.

10. Dynamically alter global simulation speed for synchronous motion.

11. Execute a battle scenario by invoking war-gaming logic and assess it through the notion of configural displays.

5. Development of the Symbolic Battlespace Visualization Framework

Effective battlespace visualization should portray information in a way that gives a user the ability to intuitively understand the state of the battle (Barnes, 1997; Haber & McNabb, 1990; Hancock, 1994; Lehner & Adelman, 1988). We conceptualize, maneuver, and interact daily in a 3-D world. Thus, it is intuitive to

visualize the battlespace in 3-D and demonstrate this intuition by creating realistic scenarios and empirically measuring combat performance as an integral part of the ABATIS architecture.

One of the most significant benefits of 3-D visualization is the ability to view graphical representations of objects from any perspective. Having the capability to visualize a 3-D object from any angle (length, width, or height) enhances the understanding of its characteristics. For example, in joint task force planning, it is necessary to provide a means of depicting air corridors and altitude. These are just two simple characteristics that 2-D representations lack. Thus, we anticipate that semantically rich designs of 3-D abstract symbology will allow the commanding officers to understand the battlespace more effectively. We envision an incremental development of concepts, based on the existing notational standard as well as on research into new ways of information portrayal. Consider, for example, the traditional mechanized battalion symbol and its evolution into the 3-D representation shown in Figure 1.

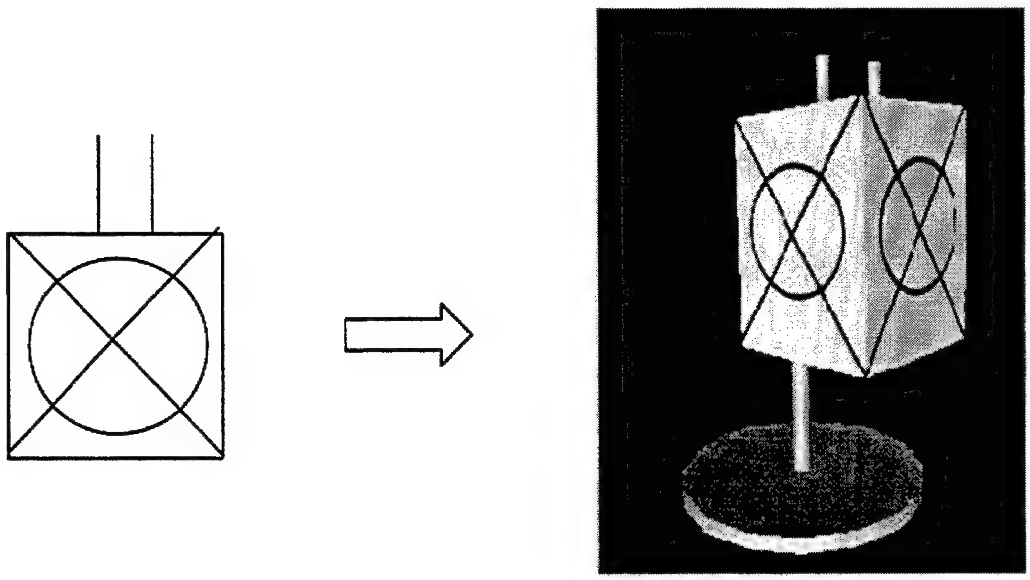

Figure 1. Evolution From 2-D to 3-D Symbology.

The 2-D symbolic representation of a battalion is composed of a square, two vertical lines, an oval, and an x-shaped symbol. The oval and the x-shaped symbol are placed inside the square to denote a mechanized unit, while the two vertical lines are placed on top of the square to depict a battalion unit. To translate the 2-D symbol into 3-D, the square is converted into a fundamental cube element, with the appropriate oval and x-shaped texture to denote a mechanized battalion unit. The two vertical lines are transformed into two small 3-D pipes. To give the battalion unit a height dimension, a flat cylinder and small pipe are used. The 3-D symbol is comprised of five separate elements (i.e., the

"footprint," the stem, the cube, and two pipes), each of which could be ascribed behavior. It is a semantically rich vehicle for information representation.

For example, the footprint could metamorphose to a real ground trace via navigational data. The stem could show actual command post (CP) locations and could be used as a barometer display for supply status. The surfaces of the cube may be used to abstract various types of diverse information (e.g., Side 1 = the strength of the force; Side 2 = estimated time to destination, etc.).

Attributes can be attached to fundamental elements to signify a particular property. For example, colors can identify the affiliation of an element via the military's standard coloring scheme. Other properties can be expressed by the available graphical elements (e.g., a wire frame representation may indicate that the object is dead).

In addition to the fundamental unit symbology, we have refined terrain rendering. Rather than relying on computationally demanding digitalizations that require considerable storage resources, we provide 3-D abstractions of terrain elements that can be used to compose the basic terrain for military scenarios.

The abstract symbology with its relevant behaviors is used to provide commanders with decision support tools such as dynamic scenario generation and synchronous battlespace animation. The dynamic scenario generation is simple and rapid. First, the terrain is composed in the scenario window. Once the terrain is established, the user can place military units (both friendly and enemy) at any location within the terrain of interest. A battle scenario can be specified interactively and enacted by synchronous battlespace animation.

6. Battlespace Scenario Execution and War Gaming: A Model-Based Approach

To afford decision support, our architecture and its process-centered display must be driven by battlespace process models capable of rapid enactment and execution of war-gaming and intelligence scenarios. Our long-term vision of the architecture is an integrated system that spans a spectrum of processing methods and underlying physical elements. This design vision is shown in Figure 2. The architecture given is for a complete system that is capable of processing raw data and being used to drive the process-centered display. The architecture is arranged into *levels of abstraction* and separated into physical and procedural layers.

The physical layers comprise

1. The Database: Intelligence data collected through various sources (e.g., imagery, human intelligence [HUMINIT], signal intelligence [SIGINT], etc.; these are "raw" data).

2. The Battlespace Object Clusters: A collection of battlespace objects abstracted through the process of intelligence production.

3. The Metaphor Object Base: Metaphors are model engines that embody procedural mechanisms for displaying the battlespace state.

4. The Process-Centered Display: The procedural layers of the architecture would enable the transitions through the physical levels. Through intelligence production, data could be clustered, categorized, and amalgamated into objects that will eventually underlie the metaphors. Knowledge abstraction and mapping procedures will facilitate this process (i.e., they will provide mechanisms that should associate metaphors with the battlespace object clusters). The visualization and process dynamics control is a set of procedures and rules governing the change of graphical element states on the PCD.

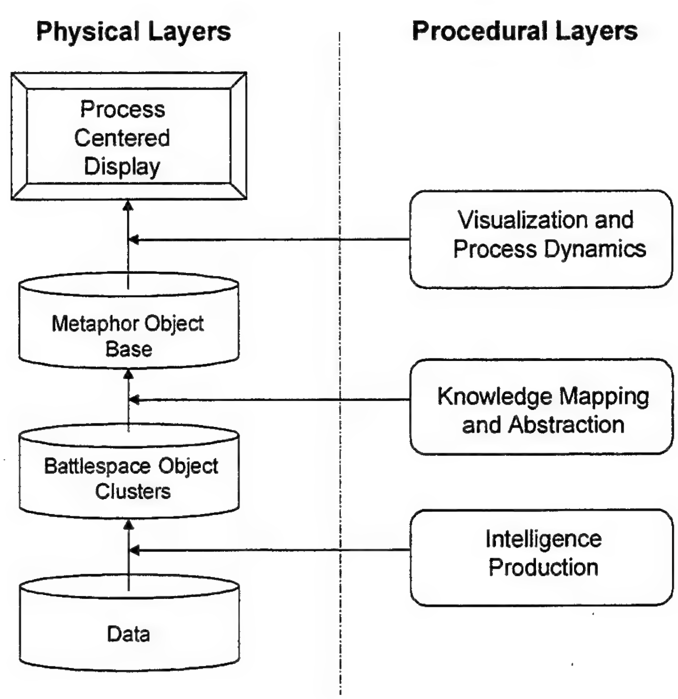

Figure 2. Integrated Battlespace System Architecture.

The procedural and physical layers are organized as modular objects that communicate by sending messages. The source of those messages can be a simulator or some other existing military software system adapted to that function. This modularity is intended to enable the PCD to "plug and play" with other commanders' decision support systems.

The three lowest physical layers are the basis for the construction of a model base intended to dynamically control the PCD. The lowest level is the raw data as they are acquired from the battlespace. These data may have many different formats and may be valid at various times in the past. For example, some data may be current, while other data may have come from sources that may be an hour old. Data at this level are relatively unorganized and unstructured.

Through the procedural application of intelligence production, the raw data are clustered or processed in some other way to produce the first level of abstraction. Battlespace object clusters are more closely related to the types of objects that commanders consider when they make tactical decisions. If a conventional user interface were applied to this level of the model, a display showing battlefield state but not battlespace processes would result.

Our approach to war gaming is based on COA generation and assessment concepts by Schlabach, Hayes, and Goldberg (1999). War gaming is the assessment of how well a specific friendly COA might perform in a battle against the enemy's COA (Kaiser & Proffitt, 1992). Therefore, as pointed out by Schlabach (Modrick, 1976), efficient COA generators and evaluators are critically needed tools that can assist the commander's decision making. The two COA generators, AirLand Battle Management and Systems for Operations Crisis Action Planning, do not facilitate assessments of how well the generated COAs would perform versus the enemy's COAs. The FOX-GA genetic algorithm-based COA generator and war gamer provides such capabilities. It uses causal reasoning to war game COA in a variety of scenarios. We plan to employ this generator in our system as the foundation for dynamic scenario execution. The FOX algorithm can provide us with the best COA and war-gaming rules, based upon which simulation model that drives the process-centered display can be built.

ABATIS is well positioned to interface with a war gamer such as FOX-GA. Figure 3 illustrates the modular design that facilitates integration with war-gaming rule bases and terrain and COA databases. Procedures that abstract those databases from a war gamer can be added.

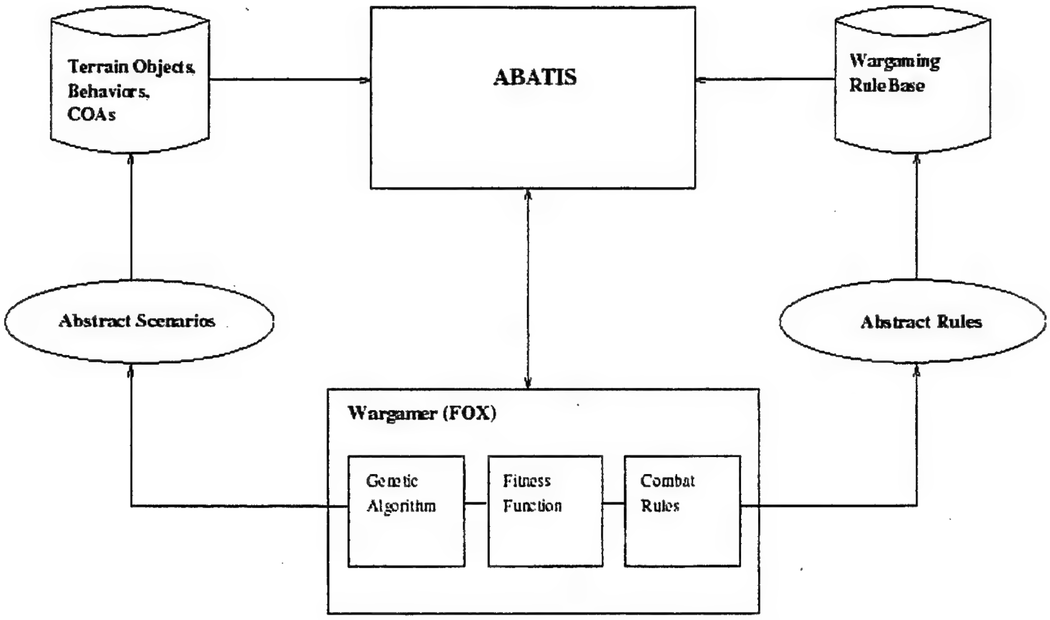

Figure 3. Integration of ABATIS With a War Gamer.

As a proof of concept, we have developed initial integration procedures wherein sample war-gaming logic abstracted from FOX is realized in an illustrative scenario.

7. An Illustrative Scenario

The scenario developed to support this research is a combined arms brigade executing a movement to contact mission. It is rather simple and straightforward in its implementation to allow rapid prototype demonstration of essential scenario dynamics rather than displaying high density, high resolution battlespace data.

7.1 The Area of Operations

The National Training Center (NTC), Fort Irwin, California, provides the geographic and operational setting for this brigade operation. The area of operations has two avenues of approach able to support multiple battalion formations. Viewing each from the vantage point of the line of departure (LD), one avenue of approach on the left allows virtually unrestricted maneuver. The other includes a significant choke point beyond the LD. Maneuver corridors for each avenue depict their relative ability to support mobility. There are three lines of defendable terrain (LDTs) beyond the LD. Friendly unit phase lines correspond with the LDTs. Each supports reasonable defensive operations by opposing forces, but there is no dominant key terrain favoring the defense. The

nature of the terrain and the mission results in the designation of two battalion sectors. One corresponds to each maneuver corridor. The battlespace representation uses abstractions of terrain and man-made features. Certain terrain features that might appear on a standard military map are not included because they are not militarily significant. The terrain representation is kept austere because it will be evaluated for its adaptivity and the utility of its terrain information content.

7.2 The Friendly Maneuver Force

The brigade includes four battalion task force maneuver elements. Initially, they are positioned in assembly areas behind the LD. The left avenue of approach is designated as the brigade main avenue of approach. The right is the supporting avenue. Two battalions are in the lead echelon on the left with a reserve unit following in sector. One battalion is assigned to the right sector.

7.3 The Opposing Maneuver Force

The opposing force is defending lightly with a platoon-sized reconnaissance element at the choke point in the right battalion sector. In the left sector, two opposing force companies are arrayed along the second LDT. Two companies and residual forces from earlier positions in the sector will defend their main defense, which corresponds with the primary objective of the friendly forces.

7.4 The War-gaming Logic

The war-gaming logic is simple and fundamentally doctrinal. It is implemented to permit activation of basic battlespace dynamics and to demonstrate the responsiveness of the system to such logic. Attackers are favored whenever their combat power meets or exceeds 3:1. Combat power is calculated on platoon counts, not individual weapons or crews. Movement is controlled at approximately 5 kph when troops are not engaged and 0.5 kph when they are engaged. Specific attrition is keyed to three levels of relative combat ratios. Reduction of available forces below 65% triggers rearward movement or commitment of a reserve, when available.

7.5 Scenario Execution

The demonstration scenario flows smoothly from construction of the operating environment through friendly unit seizure of the objective. The abstract features provide excellent awareness of the tactical situation. A static instance of the scenario (excerpted from the ABATIS process-centered display) is shown in Figure 4.

Figure 4. Instance of the Sample Scenario.

8. Summary and Research Issues

Based on the literature, we concluded that distrust of automated and decision support systems was a ubiquitous problem. Interestingly, we also found evidence that complacency and over-reliance on computer solutions stemmed from the same generic problem: lack of understanding of precisely what the computer is doing. These insights prompted a general research strategy to better understand the cognitive dimensions of using visualization as an interface between human and computerized problem solving. If the user understands and interacts with computerized solutions, then he or she can suggest, contradict, and if necessary, override computerized solutions. For this to occur, there has to be a common semantic framework between human and computer (a means of discourse) before any real synergy is possible. ABATIS is a software environment being developed to accomplish this by generating visualization concepts that will create a common semantic framework to forge efficient human-computer collaboration.

A number of important human performance issues must be resolved to expedite the semantic interface. The two identified as particularly important are effects attributable to the display of probabilistic information and effects attributable to cognitive biases, particularly, the confirmation bias. The working hypothesis is that better visualization methods will lessen the human limitations revealed in the literature. Better understanding of collaborative human-computer problem-solving characteristics will result in a semantic visualization environment that enhances dialogue between these two cognitive entities. The ABATIS environment will be the focus of our effort to understand this dialogue and to develop both principles and visualization concepts that will make future planning and re-planning a faster, easier, and more effective process.

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REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2000	Final

4. TITLE AND SUBTITLE

Soldier Performance Course of Action (COA) Visualization Aids

5. FUNDING NUMBERS

AMS: 622716.H700011
PR: 1L162716AH70
PE: 6.27.16

Contract No. DAAD17-99-P-0203

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Arizona
Electrical & Computer Engineering Dept
1230 E. Speedway Blvd.
Tucson, AZ 85721

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARL-CR-302

11. SUPPLEMENTARY NOTES

The contracting officer's representative (COR) is Michael Barnes, U.S. Army Research Laboratory, ATTN: AMSRL-HR-MY, Greely Hall, Bldg 61801, Ft. Huachuca, AZ 85613-5000 (telephone 520-538-4704).

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited.	

13. ABSTRACT *(Maximum 200 words)*

The computer revolution has resulted in extending the possibilities of battlespace visualization to the brigade commander and below. However, mobility and bandwidth considerations require that the systems be efficient to reflect the realities of modern combat. The Advanced Battlespace Architecture for Tactical Information Selection (ABATIS) is being developed to be a rapid planning and re-planning experimental environment. ABATIS's object-oriented architecture has the advantage of being able to rapidly construct a three-dimensional battlespace that will accurately represent the essential planning components of a brigade and smaller division battle environment. The basic architecture has been extended to include war-gaming logic as part of the software design, and examples are given that pertain to specific military problems. This capability will allow ABATIS to realize fully the implications of battlespace visualization by creating a human-computer synergy that encourages both human and machine to generate and evaluate possible courses of action and their consequences. The human performance implications are discussed, and particular attention is directed toward research issues related to terrain visualization, automation, decision making, and cognitive biases.

14. SUBJECT TERMS

battlespace visualization; human decision making; terrain visualization; course of action analysis; intelligent systems

15. NUMBER OF PAGES

30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	